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• N A T I O N A L •
PRECASTER

NATIONAL PRECAST CONCRETE ASSOCIATION AUSTRALIA

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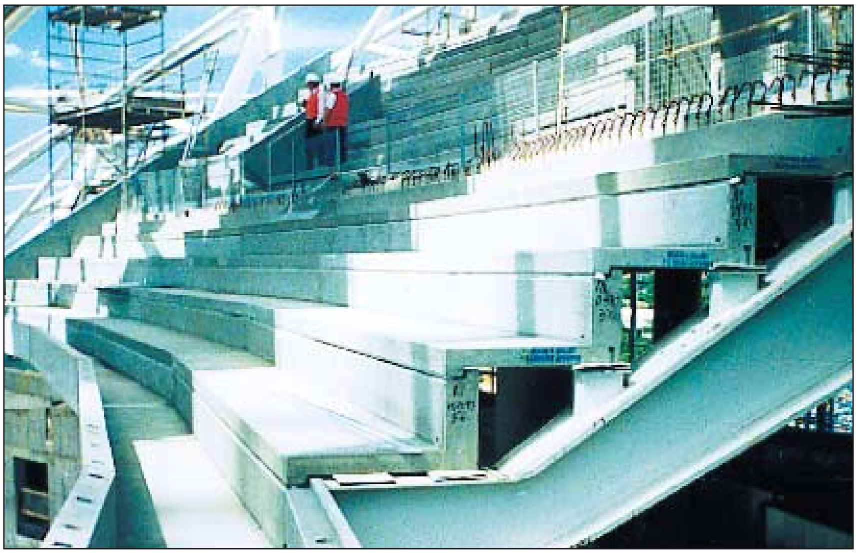


*Simple bearing connections are effective and economical*

# PRECAST Connections and Fixings

## INTRODUCTION

Connections are defined as the system or assembly used to tie a precast member to the supporting structure or to an adjacent member while fixings are the hardware component of connections.

In the design of connections structural redundancy is generally eliminated to minimise forces. Therefore, it is critically important that load paths for forces through the structure, from elements through connections down to the footings and foundation are carefully reviewed. Where possible it is prudent to design a statically determinate system, which will accommodate long-term, incremental volume-change movement. Consideration of connection behaviour during both erection and the life of the structure are important.

Practical and economical connection design must consider the manufacture of the elements and construction techniques, as well as the performance of the connections for both serviceability and ultimate limit states. Design of the overwhelming majority of connections is a simple everyday affair but the principles summarised here are the basis of all connection design.

## GENERAL DESIGN CRITERIA

Connections and fixings must meet the following criteria.

- Structural Adequacy
- Ductility
- Accommodation for Volume Change
- Durability
- Fire Resistance
- Production Simplicity
- Construction Simplicity.

**Structural Adequacy** A connection must resist the forces to which it will be subjected during its lifetime. Some of these forces are apparent, for example those caused by dead and live gravity loads, wind, earthquake, and soil or water pressure. Others are not so obvious and are frequently overlooked. These are the forces caused by restraint of volume changes in the elements (see below) and forces required to maintain stability. Instability can be caused by eccentric loading, as well as lateral loads from wind and earthquake. Measures taken to resist instability may aggravate the forces caused by volume changes, and vice versa.

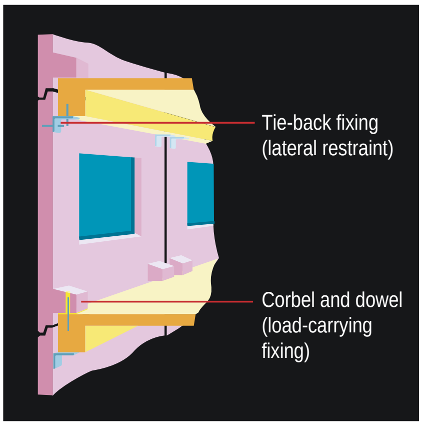
The connection resistance can be categorised by the types of force to which it is subjected. These include:

- Compression
- Tension
- Flexure
- Shear
- Torsion.

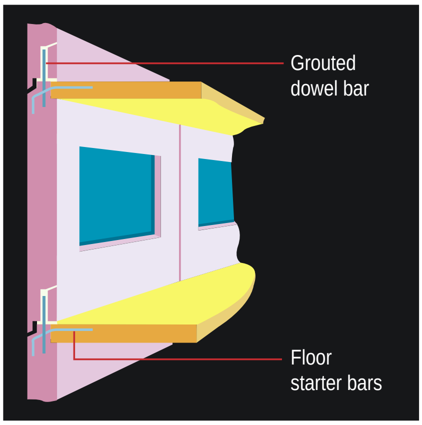
Many connections will have a high degree of resistance to one type of force, but little or no resistance to another. For example, a connection may have a high shear capacity and little or no moment capacity. For a given type of connection it may be unnecessary, or even undesirable to provide a high capability to resist certain types of forces.

**Ductility** For the purpose of design of connections, 'ductility' is defined as the ability to accommodate large deformations without failure. In structural materials, ductility is measured by the amount of deformation that occurs between first yield and ultimate failure.

Ductility in building frames is usually associated with moment resistance (rotational ductility) and in the case of precast structures may have a major impact on connection design. Flexural or direct tension is normally resisted by steel components, either reinforcing bars or structural steel sections. Connections are proportioned so that first yield occurs in this steel component, and final failure may




*Cladding panels – the most common fixing method for multi-storey buildings is elegant and economical*




*The most efficient way to utilise precast cladding is to make it loadbearing, the connection details are straightforward* be from rupture of the steel, crushing of the concrete, or a failure of the connection of the steel to the concrete.

**Accommodation for Volume Change** The combined effects of shrinkage, creep and temperature differences can cause severe stresses on precast concrete elements and their supports if the end connections restrain movement. A connection should either be able to accommodate these strains or be strong enough to withstand the induced forces, or a mixture of the two. (These stresses must be considered in the design, but it is usually far better if the connection will allow some movement to take place. This can be achieved by slotted holes or sliding bearings). Build-up of force due to these effects takes time and it can take many years before the full effects are felt.

Most of the severe problems that have been caused by restraint of volume change movements have appeared when relatively long elements such as floor deck units have been welded to the supports at both ends, eg the collapse of roof elements of a school building in Antioch after 20 years. When such elements are welded only at the top, experience has shown that volume changes are adequately accommodated. On relatively short, heavily loaded elements such as beams, an unyielding top connection may attract negative moment which is difficult to design for. Prestressed elements rarely exhibit cracking at locations further from the ends than the transfer length of the strand.

*Starter bars for a loadbearing column connection*

**Durability** A connection should be durable for the environment in which it is placed. (When exposed to weather, or used in a corrosive atmosphere, steel elements should be adequately covered by concrete, be hot-dipped galvanised or be of stainless steel. Reinforced elements should have adequate cover of quality concrete.) In marine environments stainless steel may be required for particular fixings. Dissimilar metals should not be directly coupled.

**Fire Resistance** Many precast concrete connections are not vulnerable to the effects of fire and require no special treatment. For example, the bearing between slabs or stemmed units and beams do not generally require special fire protection. If the slabs or tee beams rest on elastomeric pads or other combustible materials, protection of the pads is not generally needed because deterioration of the pads will not cause collapse. After the fire the pads can be replaced.

Other connections should be protected from the effects of fire to the same degree as that required for the members connected. The requirements in the BCA will need to be satisfied. For example, an exposed steel bracket supporting a beam may be weakened enough by a fire to cause failure and dislodge the beam from the structure. Such a bracket should be protected.

Connections which require a fire resistance rating will usually have exposed steel elements encased in concrete. Other methods of fire protection include enclosing with gypsum wallboard, coating with intumescent mastic, or spraying with fire protection material.

There is evidence that exposed steel hardware used in connections is less susceptible to fire-related strength reduction than other exposed steel elements. This is because the concrete elements provide a 'heat sink', which draws off the heat and reduces the temperature of the steel.

**Production Simplicity** Maximum economy of precast concrete construction is achieved when connection details are kept as simple as possible, consistent with adequate performance and ease of erection. Furthermore, complex connections are more difficult to control and will often result in poor fit in the field. This can contribute to slow erection and less satisfactory performance.

The following is a checklist of items to consider in order to improve production procedures:

- Connections often require congested reinforcement, embedded plates, inserts, blockouts, etc. Frequently the number of items concentrated into an area means that there is virtually no room for the concrete. In some cases, it may be economical to increase the element size just to avoid congestion. Also, details such as dapped or recessed ends should be avoided unless necessary. They require special reinforcement in a constricted area and are always congested.
- Reinforcing bars and prestressing strands or ducts, which usually appear as lines on drawings, have real cross-sectional dimensions. In the case of bars these are larger than the nominal bar diameter because of the deformations. This must be considered in the design phase.
- Bends in reinforcing bars require minimum radii, which can cause fit problems or lead to loss of cover. Generally, and especially if congestion is suspected, details of the area in question should be drawn to a scale of at least 1:5 to ensure everything can be fitted together and concrete placed and compacted. Remember elements are usually cast in forms with concrete deposited from the top and sufficient space for vibrators should be provided.
- Similar details should be identical even if it may result in a slight over-design. This will result in fewer form set-ups and improve scheduling. Wherever possible, hardware items such as inserts, studs, steel shapes, etc, should be standard items that are readily available.
- Fixings that have projections, which require cutting through the forms, are difficult and costly to place. Where possible, these fixings should be placed only in the top of the element as cast. Even this inhibits finishing of the top surface. This is important on deck elements, double tees, hollow-core slabs as well as wall panels. Cast in ferrules are preferred to projecting bolts.
- Items that are embedded in the element, such as inserts, plates, reglets, etc, require time and care to locate precisely and attach securely. Such items should be kept to a minimum.
- A precasting operation is most efficient when the product can be taken directly to the storage area immediately after it is stripped from the form. Any operations which are required after stripping and before placement at the job site, such as special cleaning or finishing, or welding on projecting hardware, should be avoided whenever possible.

*Loadbearing connections in architectural facades should be simple and not obtrusive*

- Tighter dimensional tolerances than industry standards are difficult to achieve. Connections which require close-fitting parts without provision for adjustment should be avoided.
- Inserts used for lifting should not be easily confused with inserts of a lesser capacity used as tiebacks or other purposes.
- Precast concrete manufacturers should be allowed to use alternative details, methods or materials, provided the design requirements are met. These will often result in the most economical and best-performing connections.

**Construction Simplicity** Much of the advantage of precast, prestressed concrete construction is due to the possibility of rapid erection of the structure. To fully realize this benefit, and to keep costs within reasonable limits, field connections should be kept as simple as possible. The following is a list of items that should be considered during the selection, design and detailing of connections to facilitate speedy and safe erection:

- Hoisting the precast elements is usually the most expensive and time-critical process of erection. Connections should be designed so that the element can be lifted, set, and unhooked in the shortest possible time. Before the crane can be unhooked, the precast element must be in its final position, stable and secure. Precast elements such as double tees and hollow-core slabs are inherently stable and require no additional connections before releasing the crane. Others, such as columns, deep beams, wall panels and single tees usually require some supplementary shoring, guying, or fastening before the crane can be unhooked. Pre-planning for the fewest and quickest possible operations that must be performed before releasing the crane will greatly facilitate erection.
  In some cases, it may be necessary to provide temporary fasteners or levelling devices, with the permanent connection made after the crane is released. These temporary devices must be given careful attention to ensure that they will hold the element in its proper position during the placement of all elements that are erected before the final connection is made.
- A certain amount of field adjustment at the connections is always necessary. Normal fabrication tolerances will preclude the possibility of a perfect fit in the field. This is true not only when the precast elements adjoin each other, but, even more so, when the precast elements must interface with insitu construction.

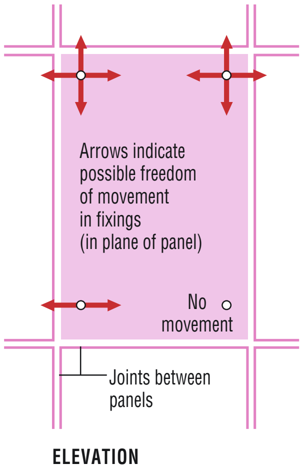



***Figure 1** Typical panel fixings*

Adjustment in the field is accomplished through the use of slotted or oversize holes for bolts and dowels, field welding, shims and grout.

- Connections should be planned so that they are accessible either from the completed structure or a stable deck or platform. The type of equipment necessary to perform such operations as welding, post-tensioning, or pressure grouting should be considered. Operations which require working under a deck in an overhead position should be avoided, especially for welding. Room to place wrenches on nuts and swing them in a large arc should be provided for bolts. Dry-packing column or wall panel bases in a narrow excavation is difficult.
- Materials such as grout, dry-pack, cast-in-place concrete, and epoxies need special provisions if they are to be placed in cold weather. Welding will require special precautions when the ambient temperature is low. Connections should be designed so that delays due to inclement weather are avoided.
- Reinforcing bars, steel plates, dowels, and bolts that project from the precast element can be damaged if care is not taken during handling and require repair. Anchor bolts that project from cast-in-place footings should be at least 24 mm in diameter so that there is less chance of them being bent. Threads on projecting bolts should be protected from damage and rust.

These production and construction considerations can be summarised as:

- Standardise products, details and hardware
- Avoid reinforcement and hardware congestion
- Avoid penetration of forms
- Reduce post-stripping work
- Be aware of material sizes and limitations
- Consider clearances and tolerances and avoid non-standard production and erection tolerances
- Plan for the shortest possible crane hook-up time
- Provide for field adjustment
- Use connections that are not susceptible to damage in handling
- Ensure the panel has stability when the crane is unhooked and allow for late adjustment for correct alignment
- Locate connections so that they may be installed on a single floor and don't require work parties on two floors at once.

## CLADDING PANEL CONNECTIONS

There are a number of important principles that should be followed in the design of connections for precast cladding units:

- Panel connections must resist the self-weight of the panel in combination with the external forces imposed on it. The primary external forces arise from wind and earthquake. Induced forces may also arise from movement of the building frame and panel creep or shrinkage. Temperature variation will also cause panels to bow and move axially, giving rise to restraint forces. All these forces can be calculated with reasonable accuracy and resisted or dispersed by simple detailing. Generally bowing and axial movement nearly compensate for each other and the small dimensional change is absorbed by the fixing.
- The panel should be attached to the building frame so as to reduce the effects of any induced forces. This means that the panel should be supported in a statically determinate manner. Thus there should be no more than two supports and two restraints. Supports and restraints should be as far apart vertically as the panel dimensions and structure permit; small lever arms allow out-of-plane rotation.
- The entire weight of the unit is carried at the one level. The restraint fixings should preferably be accessible from this level for ease of erection. The panel fixings should be carried in direct bearing if possible. The preferred fixing system to a building frame consists of two concrete haunches and two steel restraint angles. This gives a robust but flexible attachment of the panel to the structure. Dowels in the haunches resist lateral loads. Clearance holes and packing at the restraint fixings absorb building tolerances and isolate the panel from differential movement of the structure. Other support methods substitute steel fabrications for the haunch and clips for the restraint angle.
- Units should be provided with fixings as shown in **Figure 1**. The arrows show the freedom to movement that can be

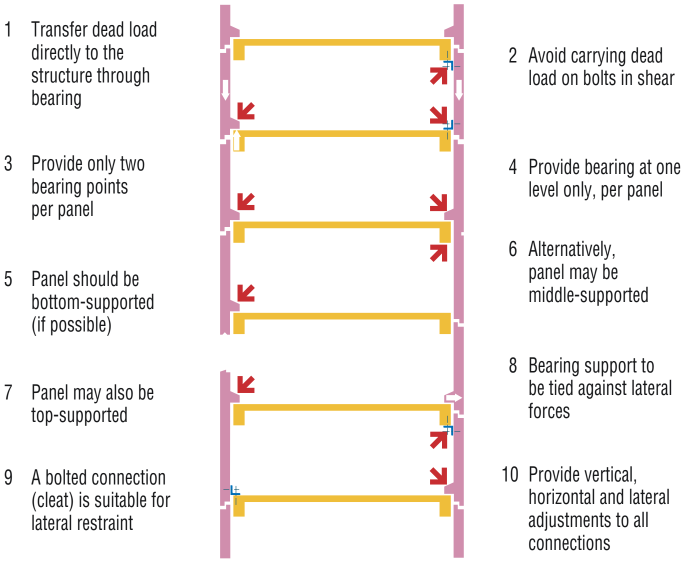



***Figure 2*** *Design principles for cladding-panel connections*

provided at each of the fixings in the plane of the panel. Each of the fixings must provide resistance to wind and earthquake forces perpendicular to the plane of the panel. These may augment gravity forces.

- Connections should be chosen so that the loads are transferred through the connections as simply as possible with minimal eccentricities. The design of the component fixing must allow for the forces and moments in the detailed design **Figure 3**.
- Connections should allow economical fabrication of the precast elements. The hardware should not interfere with concrete placement, cause finishing problems nor make it difficult to provide the specified cover to reinforcement.
- Connection details should be standard-ised as much as possible. This results in economy, speed and simplicity during production and erection, and also reduces the chance of error.
- Connections should be detailed so that hoisting equipment can be quickly released. It may be necessary to provide temporary connections that are released after final adjustments are made.

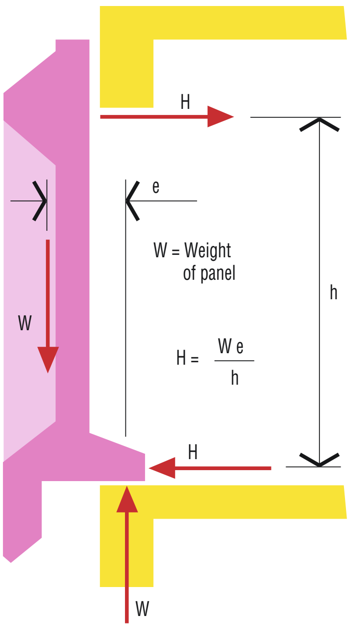
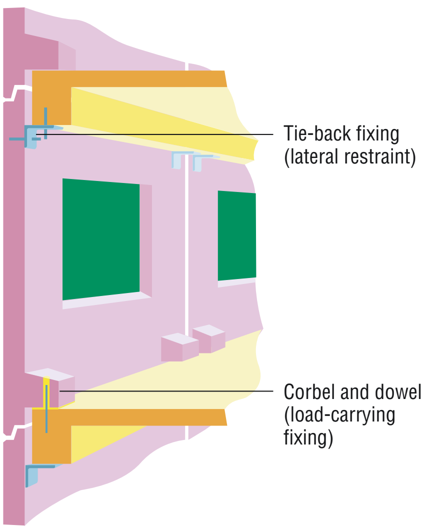
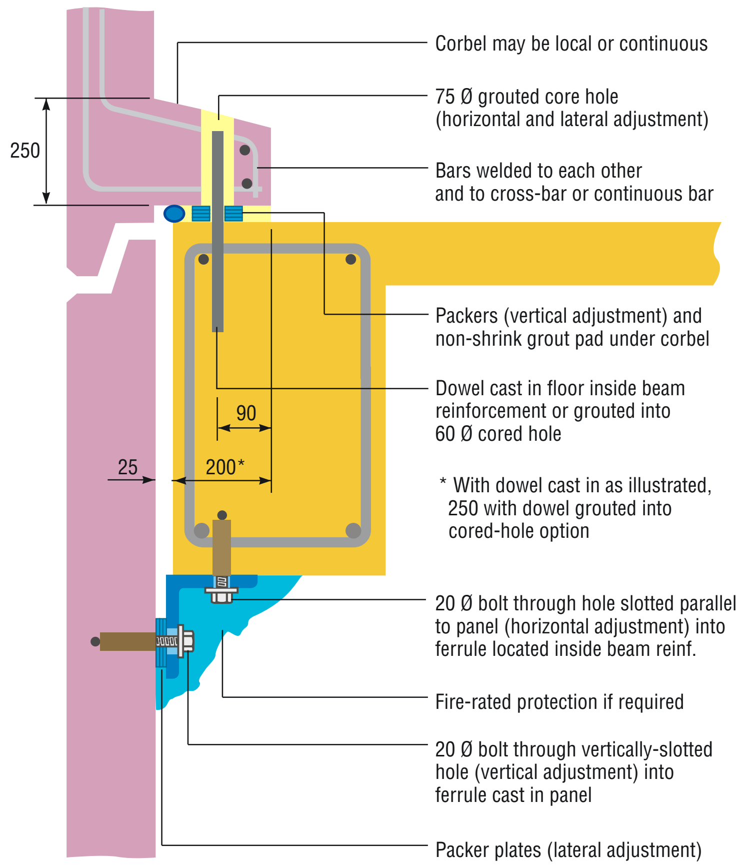



***Figure 3*** *Eccentricity of gravity forces*

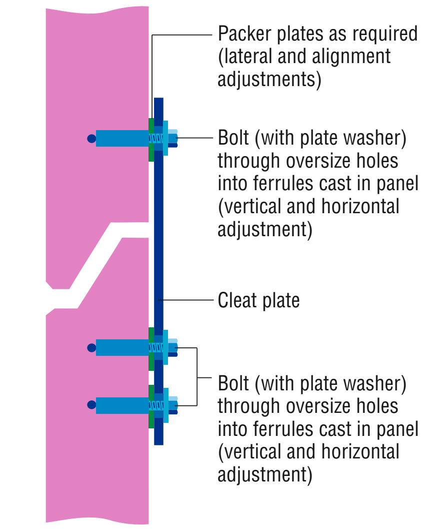



**GENERAL ARRANGEMENT**




**CONNECTION DETAILS**

***Figure 4*** *Concrete or steel corbel bearing connections*




NOTE: Lower panel must have lateral restraint (eg, a corbel)

***Figure 5*** *Restraint connections*

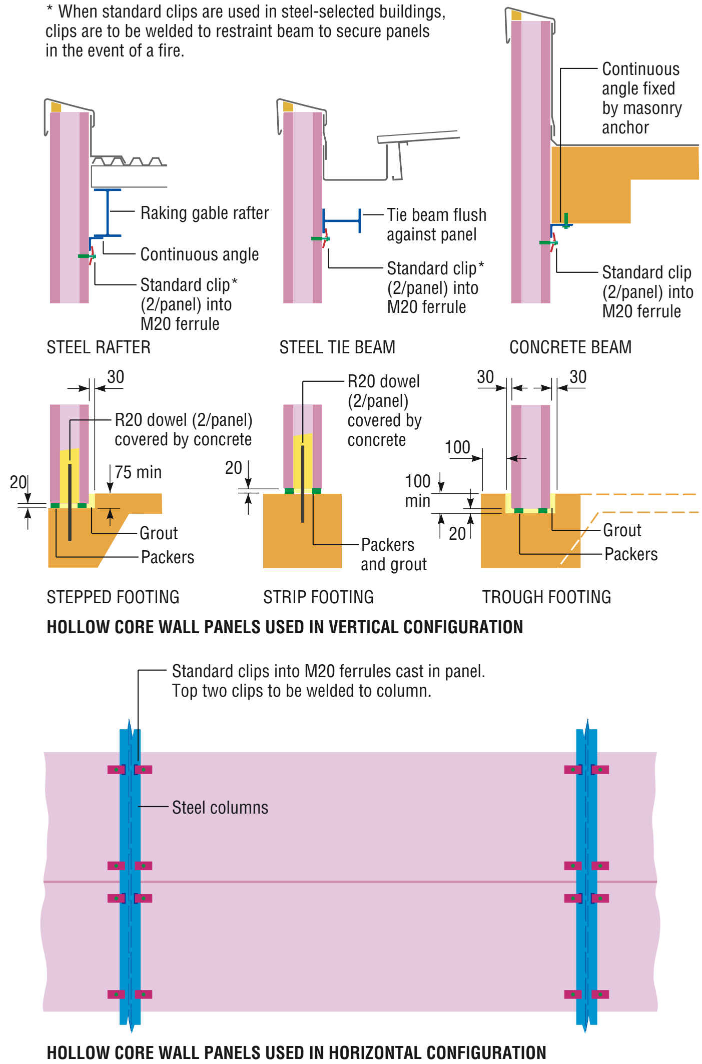



***Figure 6*** *Hollowcore panel connections*

**Cladding Panel Connection Categories** There are many possible combinations of anchors, plates, bolts and angles, etc to form various connection assemblies. However, there are two basic categories of panel connections – bearing and restraint.

**Bearing Connections** Bearing connections transmit load by direct bearing of one unit on another or the structure. Particular care should be taken in the detailing to prevent cracking in the supported as well as the supporting member.The interface material must cater for the vertical, horizontal, and rotational forces.

Some form of variable-thickness packing material is necessary to absorb tolerances (eg mortar or shims).

High bearing-intensities may be developed at edges of a bearing surface due to deflection and twisting of the supported member, as well as mismatching of the bearing surfaces. This can cause cracking and spalling unless they are taken into account or avoided in the design of the connection. Chamfered or protected edges will alleviate this problem.

- **Haunches** These can be either concrete or steel. A typical concrete corbel or haunch cast on a cladding unit is shown in **Figure 4**. It can also be fabricated from a rolled steel section such as an angle or channel, a plate on edge, or for light-weight units (up to 3t) a plate on flat.
- **Angle seat bearing connections** Other items used to support cladding units are steel angles. Depending on the load to be supported, the angle may need to be stiffened. Note that confinement reinforcement is needed around the embedded ferrules to add ductility to the connection.

**Restraint connections** These stabilise the panel against out-of-balance gravity loads and resist horizontal windloads. For ease of erection they should preferably be accessible from the same lever as the support fixings. The simplest is an angle as in **Figures 5**. Panel-to-panel restraint connections can also be used in the horizontal direction to hold adjacent panels together.

**Hollowcore panel connections** Hollowcore panels are usually non-loadbearing cladding panels. They may be single-storey panels spanning vertically or horizontally and are fixed to the building frame. The frame can be of steel or concrete. Details of typical fixings at the top and bottom of the panels are shown in **Figure 6**.

## LOADBEARING CONNECTIONS

**COLUMN ELEMENTS** The connections of a column element must be detailed to carry the required design loads in service and allow quick and easy erection. There are a number of means of splicing or connecting columns into a structure; the two most common are by grouted dowels and by steel base plates. Precast concrete units are accurately made factory products. Advantage can be taken of this by connecting precast to precast.

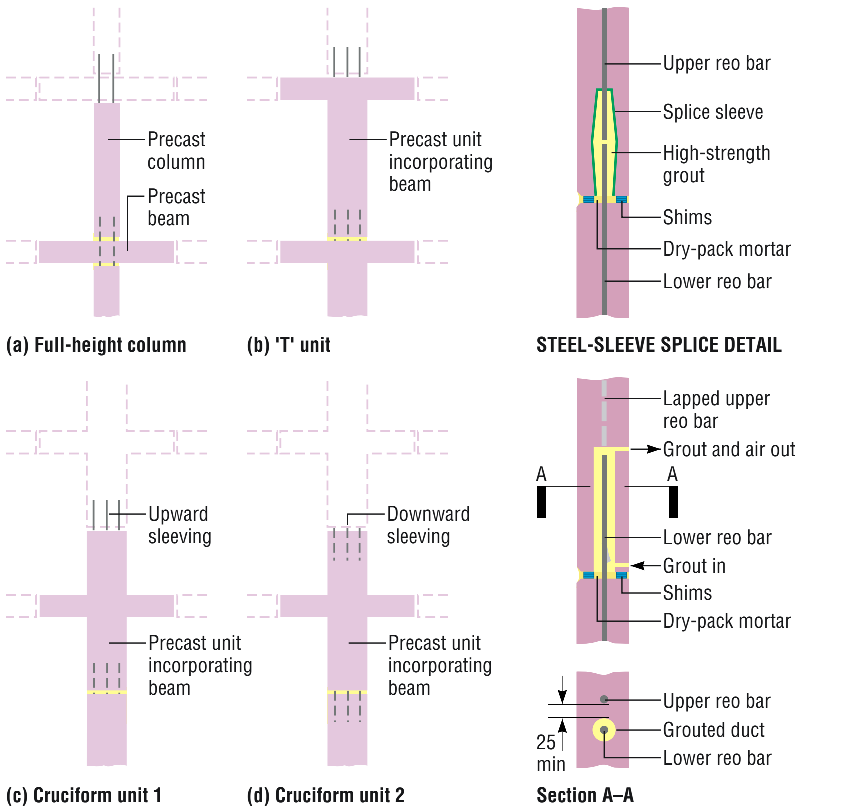
### Column connection detail principles

- The column length between splices should be as long as possible to minimise the number of joints and the number of pieces to be erected. A typical length would be 2 stories in multi-storey construction. Three stories is a normal maximum. The frame must be braced and not rely on the splice for frame stability.
- The connection should be easily accessible during construction. Locate it in a zone between floor level and say, 1.5 metres above the floor. The latter will place it where bending is a minimum. Where there is a change in column section, locate it at floor level.
- The type of connection is selected on convenience and cost. The most convenient is the bolted baseplate; the most economical is the grouted pocket. The grouted pocket is usually only used at foundation level. A baseplate connection is the quickest to erect. Plumbing is by adjusting the holding down bolts, the column is immediately stable and the crane can be released. The baseplate is flush with the outside of the column for intermediate splices. In this case the bolts are housed in recesses at the corners of the section.
- Dowelled connections are economical but require the column to be separately stabilised until grouted. Two or three props are required for stability. These are secured to the main structure and are adjustable for plumbing of the column.
- There are a number of techniques for forming the dowelled splice. Usually the column bars project from the unit below into core holes formed in the unit above. This can allow an in-situ floor slab to be carried directly on the column with the bars projecting through. Proprietary grout sleeves are available to form the core hole, these minimise the bond length required. The column bars may also project from each unit and connected by welding to splice angles or by fusion. However this requires very accurate construction.
- The number of bars to be spliced at the joint should be a minimum to avoid congestion and simplify erection. Eight bars is a practical maximum. Load can be transferred through the connection by bearing, with most of the column bars being discontinuous. Extra ties may be required to carry local stresses.
- The mixing of the grout must be properly controlled to ensure that the design strength is achieved. Premixed and proprietary grouts are the best means of doing this. The designer should examine the products available and specify a particular product type rather than employ generic names such as *non-shrink* grout.
- Core holes may be grouted by pouring directly into access holes in the side of the column or by pumping into holes drilled into the duct near the base. This ensures that all air is displaced, see **Figure 7**.
- The duct size must be large enough to provide sufficient erection tolerance and clearance and to permit free flow of grout around the bars. Generally, a duct size two and a half to three times the bar diameter is satisfactory. The horizontal joint between units must be wide enough to provide adequate tolerance and to permit free flow of grout throughout the bearing area. A width of 20 to 25 mm is generally adequate.
- The pressure of the grout at the joint can be considerable. A one-and–a-half metre head will lead to a pressure of 36 kPa. Thus the joint needs to be very securely sealed.

**WALL ELEMENTS** The design of connections for load bearing wall elements follows principles similar to those given above for column units. Loads are transmitted either by direct bearing or by dowelled connections. Close attention to detail, planning, manufacture and site activities is required.

### Wall unit connection detail principles

- Generally the principles given for column units above apply. Reference should be made to these.
- Load transfer is through grout or dry-packed mortar. **Figure 8** shows typical examples: (a) with the horizontal joint at slab level; (b) similar but with the joint clear of the floor where it is more accessible and visible; (c) a thickened wall panel where a double row of long dowels provides moment resistance as well as bearing support.
- Lateral joints are left open or are connected by insitu grout or concrete infill sections.
- Hard packers used for levelling during erection must be removed. These create a stress concentration that may lead to vertical splitting and spalling of the unit. Plastic packers or similar, which can deform under long-term load, should be used when they must be left in place. The packers should be located at points where a stress concentration would be least critical.




TYPICAL COLUMN SPLICE CONFIGURATIONS

DUCT SPLICE DETAIL

***Figure 7*** *Typical loadbearing column connections*

- Progressive collapse must be considered in load bearing wall panel construction. Providing alternative load paths in the structure by continuity of reinforcement across joints does this.
- Realistic erection tolerance should be provided for.
- Loading from floor and roof structure usually applies eccentric loads on wall units. Connections and the members must be designed for realistic eccentricities.
- Details for shear connection between panels to form shear walls are shown in **Figure 9**.

## BEARING PADS

Bearing pads are used to distribute vertical loads over the bearing area. Some pads also reduce force build-up at the connection by permitting small displacements and rotations.

There are several materials commonly available as bearing pads. In some cases, various grades are available in the same material and they exhibit different properties and behaviour. In case of doubt, consult the pad supplier or precast manu-facturer for proper selection of the pad. Most pad manufacturers have technical brochures available to aid the designer.

Bearing pads typically belong to one of the following categories:

- Commercial grade elastomeric pads are readily available. However, these pads exhibit wide variations in shear-deformation characteristics and bearing strength. These pads are not recommended unless performance data is available.
- Structural grade chloroprene pads used in places where uniform bearing is necessary or when it is desired to reduce volume change restraints. For high compression stresses and/or large horizontal displacements, laminated pads consisting of layers of elastomer bonded between steel or fibreglass plates can be used. Each layer behaves in compression like an individual pad, but the shear deformation is a function of the thickness of the total assembly.
- Laminated fabric bearing pads composed of multiple layers of 190 g/m$^2$ cotton fabric with a high quality binder are generally used where a higher compres-sive strength is desired. These pads do not deform as readily as elastomeric pads, and thus provide less tolerance of horizontal movement and rotation than do chloroprene pads.
- Pads reinforced with randomly oriented fibres have been used successfully in recent years. Vertical load capacity is higher than plain chloroprene pads, but tolerance of rotation and horizontal movement is somewhat lower than chloroprene pads. No national standard specifications are available for this material.
- A multi-polymer plastic bearing strip is manufactured expressly for bearing purposes. It is a commonly used material for the bearing support of hollow-core slabs, and is highly suitable for this application. The material has a compres-sive strength higher than the typical design range of concrete used in precast construction. Research has shown that most of the stress-relieving characteris-tics of elastomeric bearing pads are due to slippage instead of pad deformation.

Tempered hardboard strips are also used with hollow-core slabs to prevent concrete to concrete bearing. However, they should be used with caution in situations where moist conditions exist.

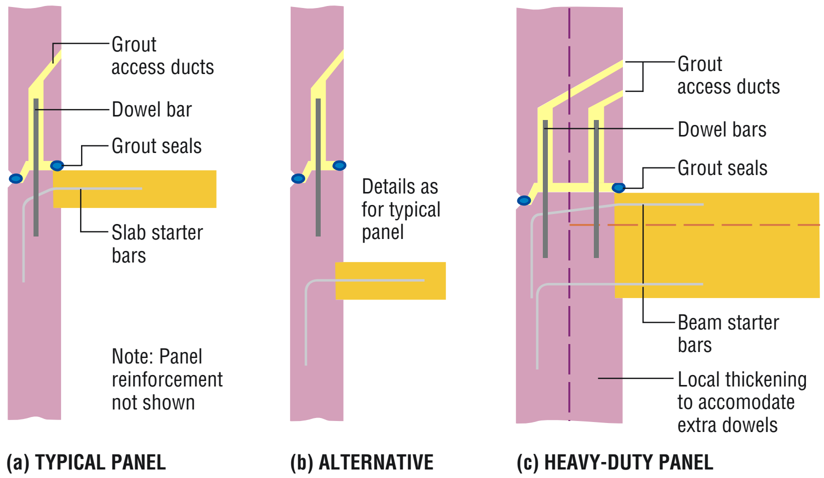



***Figure 8*** *Typical loadbearing wall connections*

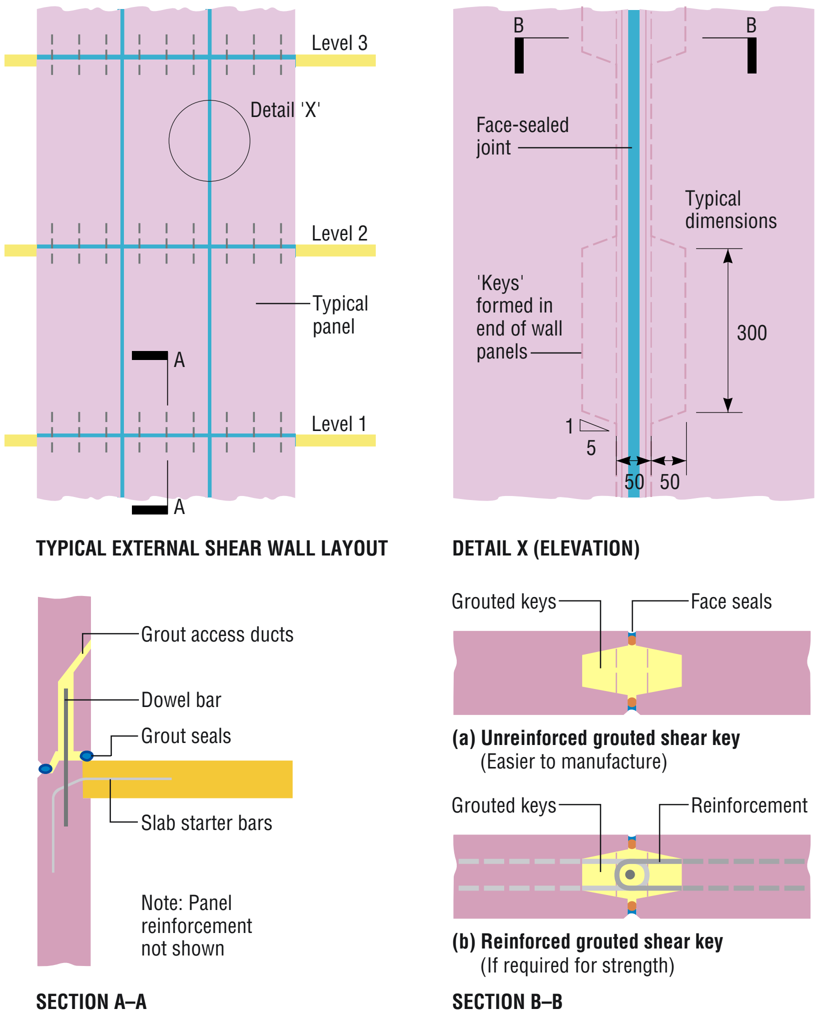



***Figure 9*** *Shear wall details*